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Acquisition of in situ and Remote Sensors for Measurements of Aerosols and Chemical Species

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6. AUTHOR(S)
Antony D. Clarke, Shiv K. Sharma and John N. Porter

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Hawaii, School of Ocean and Earth Science and Technology (SOEST)

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Office of Naval Research
800 North Quincy Street
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13. ABSTRACT (Maximum 200 words)
Under this grant, the University of Hawaii has acquired instrumentation to relate remotely sensed lidar backscatter signals to both *in situ* measurements and to satellite derived radiances. These instruments include a turn key pulsed Nd:YAG and Ti-sappire tunable laser transmitter and 12" lidar scanner, these are now part of SOEST scanning lidar system. The *in situ* characterization instrumentation package includes forward scattering spectrometer probe (FSSP), GPS receiver and a portable satellite receiving station that would be deployed with lidar and *in situ* measurements to extend the range of observations and put these in broader context. These instruments are currently being used for studying coastal marine aerosols as a function of meteorological conditions on the island of Oahu. Current activities using this instrumentation are being supported by ONR grant nos. N00014-96-1-0320 and N00014-96-1-0317.

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Atmospheric sensors, lidar, scattering spectrometer, satellite station

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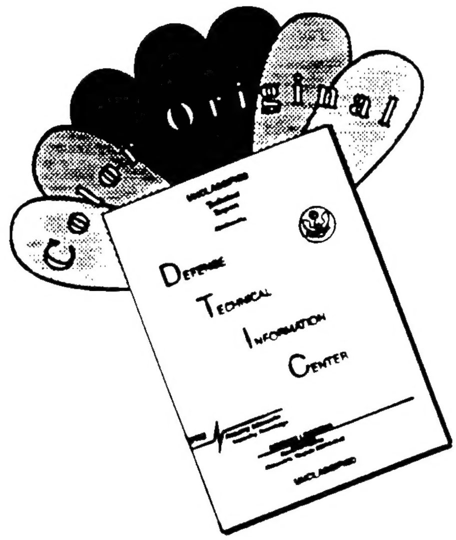

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Final Report

GRANT NO.: N00014-95-1-0217

PRINCIPAL INVESTIGATOR: Antony D. Clarke

CO-INVESTIGATORS: Shiv K. Sharma and John N. Porter

ORGANIZATION: University of Hawaii, School of Ocean and Earth Science and Technology (SOEST), Honolulu, HI-96822.

GRANT TITLE: Acquisition of In-situ and Remote Sensors for measurement of Aerosols and Chemical Species

PERIOD OF PERFORMANCE: December 12, 1994 - November 30, 1996

OBJECTIVES: Our primary objective was to acquire instrumentation that will allow the University of Hawaii (UH) to link existing expertise and existing facilities into a unique experimental package that can be directed at the characterization and quantitative measurements of aerosol and gaseous species in the troposphere. To meet this objective, we proposed to acquired following instruments to relate remotely sensed lidar backscatter signal to both in-situ measurements and to satellite derived radiances.

1). A turnkey high power and pulsed Nd:YAG and Ti-sapphire tunable laser system and a 12-inch diameter lidar scanner system, and
2). A Forward Scattering Spectrometer Probe (FSSP), GPS receiver and an aerosol light absorption soot photometer, and a portable satellite receiving station.

ACCOMPLISHMENTS:

We have acquired all the instrumentation with the funds provided by ONR under FY 94 Defense University Research Instrumentation Program (DURIP) and Matching Funds provided by the University of Hawaii. The pulsed laser system and the scanner are now the part of SOEST scanning lidar system. The *in situ* instruments and satellite receiving stations have been obtained and tested. All of the above instrumentation is operational and currently being deployed in the field. These instruments are being used to investigate marine aerosols in coastal areas as a function of meteorological conditions. These current activities using these instruments are being supported by ONR grants # N00014-96-1-0320 and # N00014-96-1-0317.

Following is a brief description of the hardware and software that have been integrated into various instruments.

A. In Situ Instrumentation: Under this award, Dr. Antony Clarke was responsible for the acquisition of aerosol and microphysics instrumentation. These included the following instruments:

FSSP 300x - Forward Scattering Spectrometer Probe from Particle Measurement Systems, Boulder Co. Provides partical size from 0.3 to 50 μm.
This instrument was obtained and tested and then sent to Droplet Measurement Systems (Boulder, Co) for custom modification to add new electronics and software capabilities including an new dual range sizing capability. Modifications after initial tests have been made and it is now being prepared for field deployment. It will provide for sizing of the large aerosol (such as sea salt) during ground based and aircraft deployments. These are required inputs for our coastal aerosol model.

GPS - The original ASHTEK GPS we were going to buy was replaced with a newer Garmin unit and Sager computer since it provided better features and weight for aircraft deployment.

ASAP - The savings for the GPS system were used to purchase an aerosol light absorption soot photometer (with approval of S. Ackleson) in order to characterize the aerosol light absorption coefficient in conjunction with our other optical instrumentation. This will be used with the scattering coefficient derived from our nephelometer to establish the total extinction coefficient for use in modeling aerosol optical properties.

All of the above instrumentation is operational and currently being deployed in the field as part of our ONR grant #N00014-96-1-0320. These activities are directed at lidar calibration and interpretation in coastal setting.

B. *Satellite Receiving Station*: Under this award, Dr. John Porter was responsible for the acquisition of satellite receiving station instrumentation.

A complete satellite receiving station was purchased from Quorum. This system allows us to collect AVHRR images from the polar orbiting satellites. As stated in the proposal, this system is designed for field experiments and not to compete with existing measurements being made in Hawaii by Pierre Flament, Torben Nielson or the National Weather Service. The system can be deployed in the field along with lidar and *in situ* instrumentation depending on the requirment of each experiment and availability of funding. The system will also be used for future field experiments (e.g., INDOEX experiment in either 1998 or 1999 pending funding) . The system uses a PC to collect the image and then they are transferred to a Sun computer for analysis. Sun computer software became available at UH, and therefore, some of the funds were used to purchase computer hardware. Products which are derived include aerosol optical depths, column integrated water vapor and vertical profiles of temperature. Cloud properties can also be derived.

Several components of the system have been tested and are currently being used by Pierre Flament to maintain AVHRR image collection here in Hawaii. During field experiments, we will use the system to derive real time maps of aerosol optical depth in the coastal areas and water vapors. These measurements will be used to guide and interpret aircraft missions. We are currently improving existing satellite retrievals and develop new models which will derive new aerosol products. Examples of these are given in Figs. 1 and 2.

C. *Lidar Instrumentation*: Under this award, Dr. Shiv Sharma was responsible for the acquisition of lidar instrumentation. Following is a brief description of hardware and software of SOEST scanning lidar system:

1. *Hardware & Software*:

Figure 3 shows the components of our LIDAR system, which is housed inside a 6X2.5X2.5 m metal shipping container. A retractable DFM Engineering scanner consisting of two 0.3 m diameter moveable plane mirrors and the following laser transmitters, acquired under this grant, have been installed in the container: (i) A high power Nd:YAG laser system (Continuum Powerlite Model 9020) capable of radiating collinear laser beams of 8 nanosecond pulses at 1064 nm ($\leq$ 1.6 J), 532 nm, 355 nm and 266 nm, and (ii) a MIRAGE 800 tunable Ti-sapphire laser system (range 710 - 910 nm). The Mirage 800, when pumped with 450 mJ of 532 nm beam from frequency doubled Nd:YAG laser, produces tunable pulses in the 710- 800 nm range with 100 mJ at 800 nm. Tunable out put of the Mirage in the 720-820 nm region would allow detection of water vapor fields using the DIAL technique. The lidar has been built inside a mobile container, that has all necessary power, air conditioning and water connections.

The retractable DFM scanner is used to transmit and receive the transmitted beam from the Continuum 9020 20Hz/32W laser. After expansion of the laser beam to a diameter of 5 cm, this beam is reflected off a remotely contolled mirror mounted on top of the secondary mirror of a 0.28 m diameter Schmidt-Cassegrain telescope, used to receive the backscattered radiation. An integrating sphere coupled through filters to fast photo-diodes using fiber optic cables is used to sample each of the transmitted pulses in order to obtain the transmitted pulse energies each wavelength. After passing through narrow band width (BW) 1 nm filter, the 532 nm backscattered radiation is collected by a gated Thorn/EMI 9863 photomutiplier tube (PMT), with PMT counts being integrated in 5 nano-second (ns) wide bins using an SRS430 multichannel scalar (MCS). The 1064 nm radiation is collected using an EG&G C30954 GaAs Avalanche Photo Diode (APD). After low-pass filtering, the APD signal is digitized using a 60MHz GAGE 6012 12-bit ADC, mounted in a PC which acquires and stores the data on 1GB removable cartridges. The controlling software package is written in 16-bit C running under Windows 95. A detector package is under development for acquiring Raman signals, multi-wavelength Mie-Rayleigh signals at 355, 532, 1064 & 1540 nm and water DIAL signals under the our ONR grant # N00014-96-1-0317.

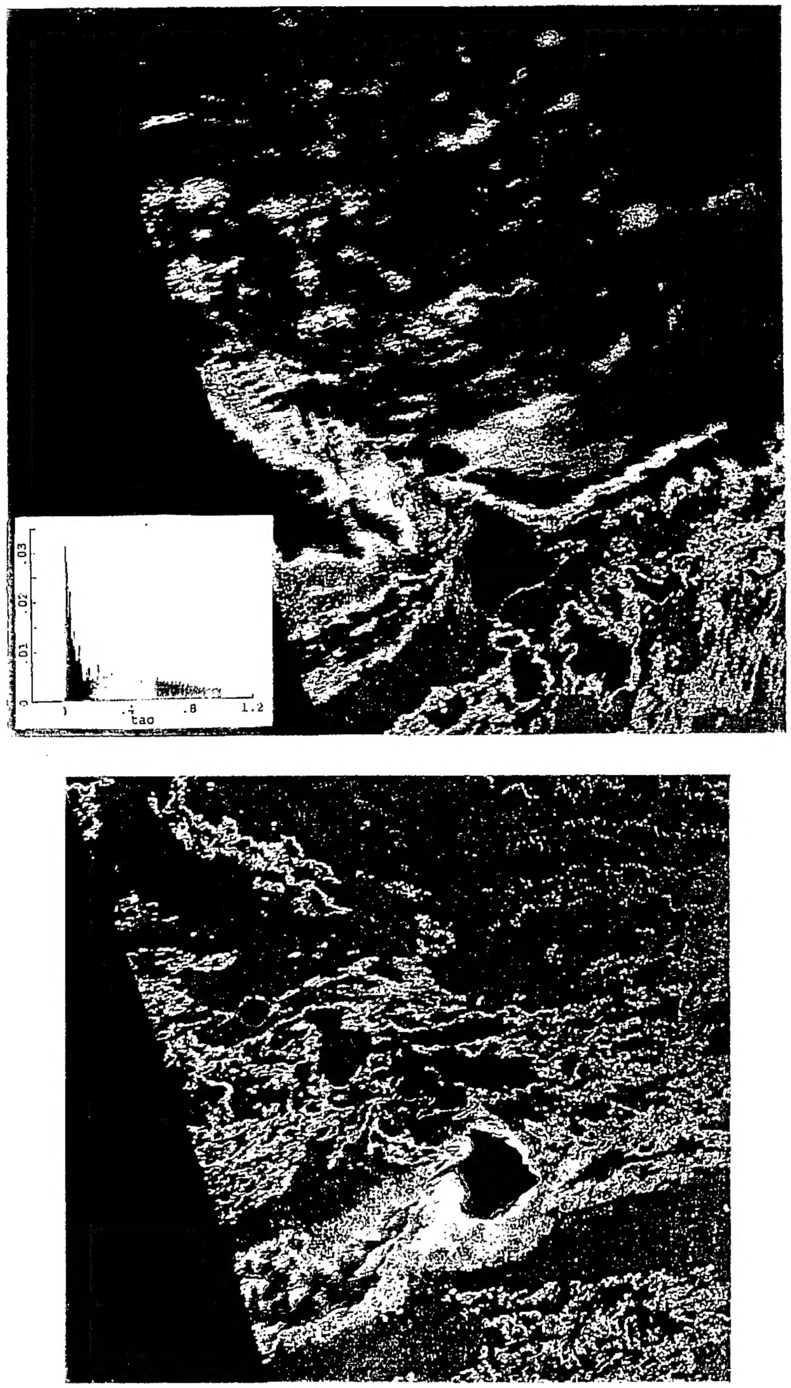

Figure 1: Images of the aerosol optical depth. In these images both the land and clouds have been flagged and set to black values. A color histogram is provided showing that for these images yellow/orange corresponds to an optical depth of 0.3. The top panel shows Asian dust/pollution to the north of the islands and clean air to the south. Asian dust/pollution events occurs every spring. The bottom panel shows the Hawaii VOG around the big island and slowly drifting downwind. For this case, the winds were light and the land/sea breeze has spread the VOG all around the island. The original AVHRR images were collected by Pierre Flament.

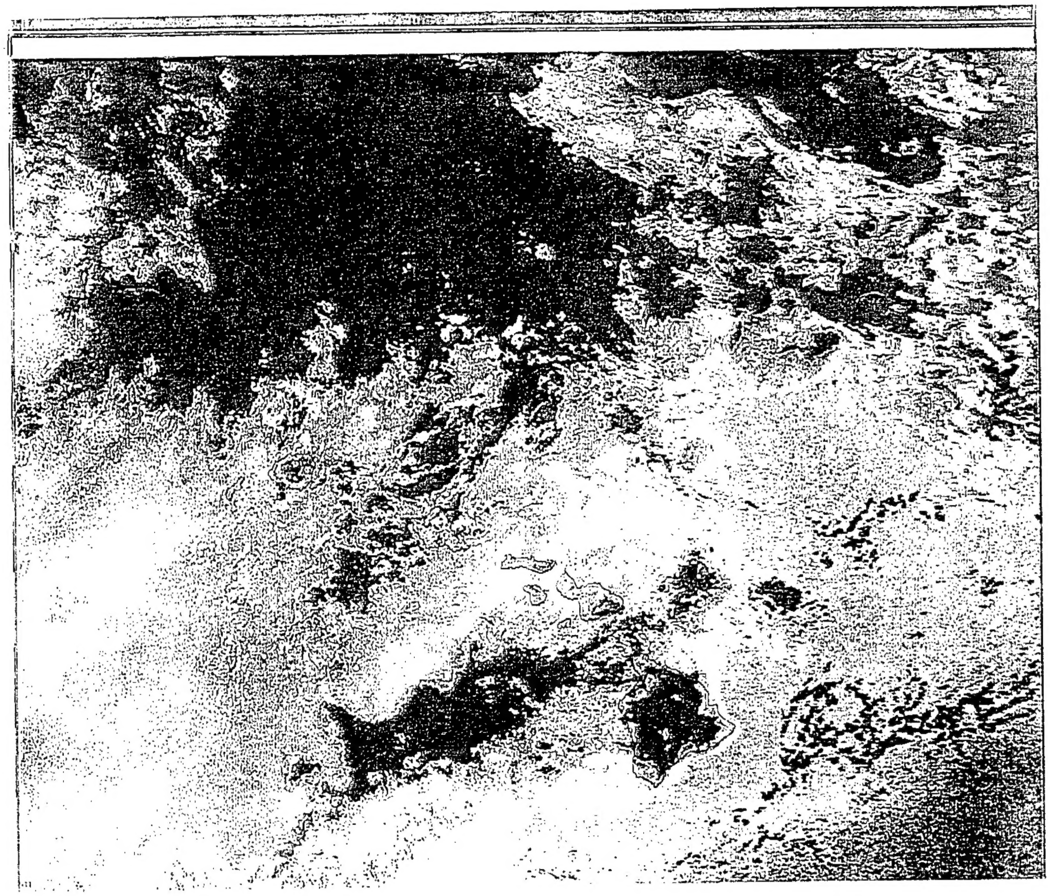

Figure 2. An image of integrated water vapor. This image shows a case with southwesterly flow over the Hawaiian islands. Regions of high water vapor (orange is above 50 mm water) are shown on the left half of the image and it can be seen that they are feeding into the deep clouds to the north. On the right side of the image, the integrated water vapor concentrations are lower and are typical of trade wind conditions (blue is ~25 mm water). These strong gradients in water vapor are associated with synoptic and mesoscale air mass modifications and are expected to affect boundary layer optical properties.

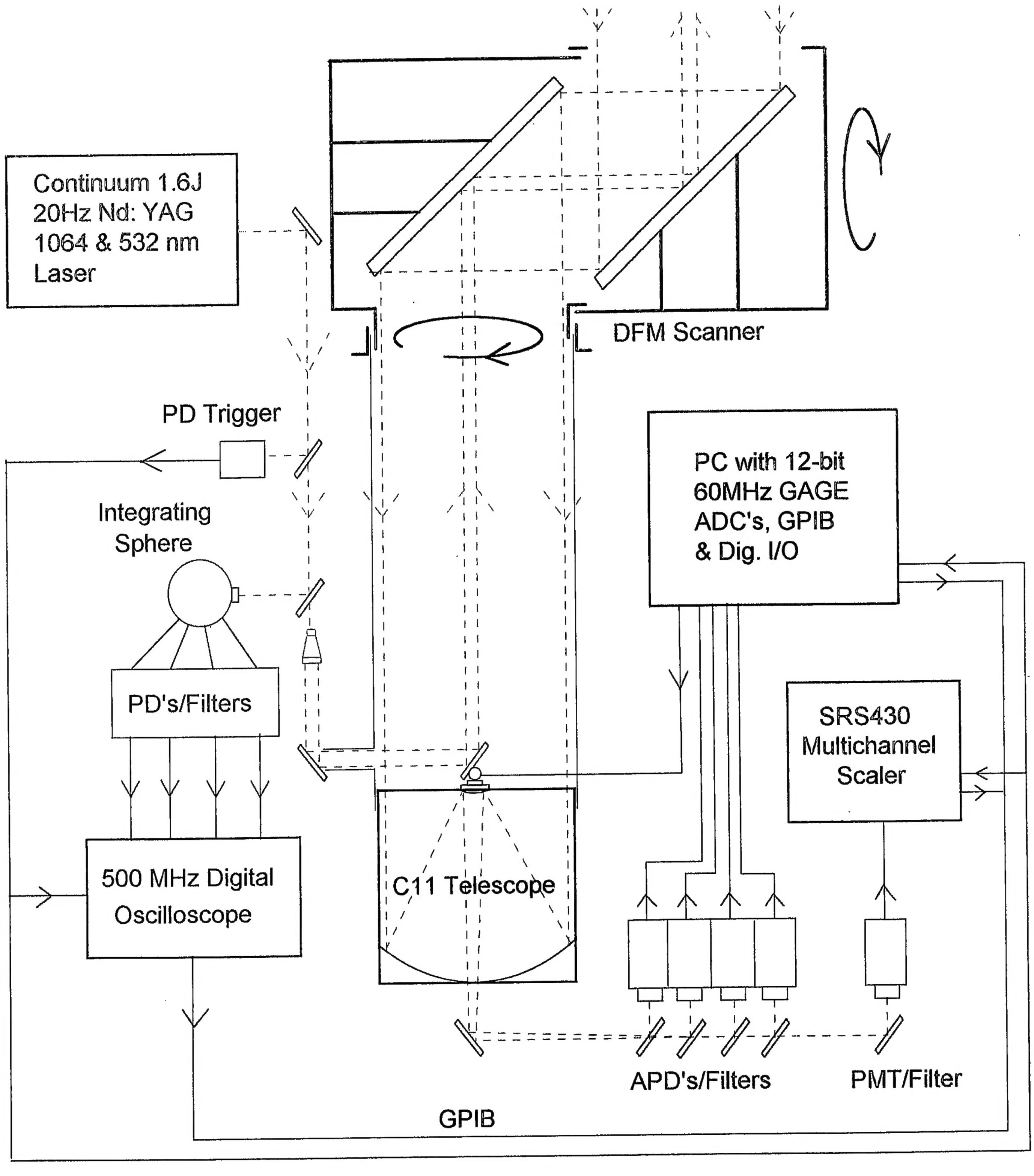

Fig. 3. Schematics of SOEST scanning lidar system. The laser system and scanner were acquired in part with DURIP- ONR funding.

Figures 4 (bottom photograph) shows the LIDAR container at its present site at Makapu'u (Makai Pier), on the Northeast side of the island of O'ahu as well as a view of Waimanalo Bay, looking Northwest towards the SOEST Aerosol Studies Group's site at Bellows Beach AFS (Fig. 4- top photograph). This facility is now operational and we have collected some preliminary data.

(ii) *Data Reduction*:

Data from each laser shot are accumulated in 8192X5 ns bins in the SRS430. When the required number of stacks are obtained, the 8192 accumulated bin counts are downloaded to the host PC, along with averaged pulse energy data from the LC9374. Each SRS430 bin count is first corrected for instrument scale factors, then divided by the calibration pulse energy. After applying detector and near-field optical corrections, the bin counts are digitally low-pass filtered. The scattering coefficient is then successively evaluated in each time bin interval by estimating the interval's aerosol scatter, dividing this by the cumulative transmission losses, then subtracting the molecular scatter (Klett approach). In this preliminary study, we have assumed a constant value of 0.6 for the aerosol phase function at 180 degrees. Initial comparison of their approach with simultaneous nephalometer measurements gave excellent agreement.

Figure 5 is a composite plot of three 10,000 shots (500 second) stacks of the green laser (532 nm, 20mJ) fired at angles of 10°, 30° and 90^0 to the horizontal. For the 10° and 30° cases, we have converted slant range to vertical distance to obtain an estimate of the vertical variation in aerosol scattering coefficient. In this way, we were able to obtain the scattering coefficient at altitudes of less than 0.5 km, the minimum range at which the LIDAR return signal is unaffected by the photomultiplier gating transients. For comparison, we have also shown the vertical variation in aerosol scattering coefficient calculated from aircraft FSSP data collected east of Tasmania during ACE 1 (Aerosol characterization experiment)(Δ, open triangles) in a low-wind regime, and off the west coast (○, open circles) in a high wind regime. The open square (□) is a simultaneous nephelometer measurement of scattering coefficient adjacent to the lidar container. These data clearly show that the aerosol scattering coefficient calculated from our lidar data fall between these two cases and appear reasonable.

Figures 6 shows the calculated scattering coefficient (m^{-1}) for 1000 laser shots (532nm excitation, 20mJ), and three sequential 100 shot (5 second) stacks parallel to and 5 m above the ocean surface. The windspeed was 8 ms^{-1} coming from the Southeast. A digital 4-pole 500ns low-pass filter has been applied to the data which was sampled in 5 ns wide time bins. The scattering coefficient for the 1000 shot average varies approximately 30% about a value of 7-$8x10^{-5}$ m^{-1} which was measured by a nephelometer outside the LIDAR container, except at two distances (0.6 and 1.2 km), where waves were breaking over reefs. The large differences between the three 100 shot traces give some indication of the large variability in scattering coefficient with both time and distance. It is anticipated that Raman and multi-wavelength lidar data in conjunction with simultaneous *in situ* measurements in coastal marine environments provide a better understanding of the variation of electro-optical extinction coefficients in the UV to near

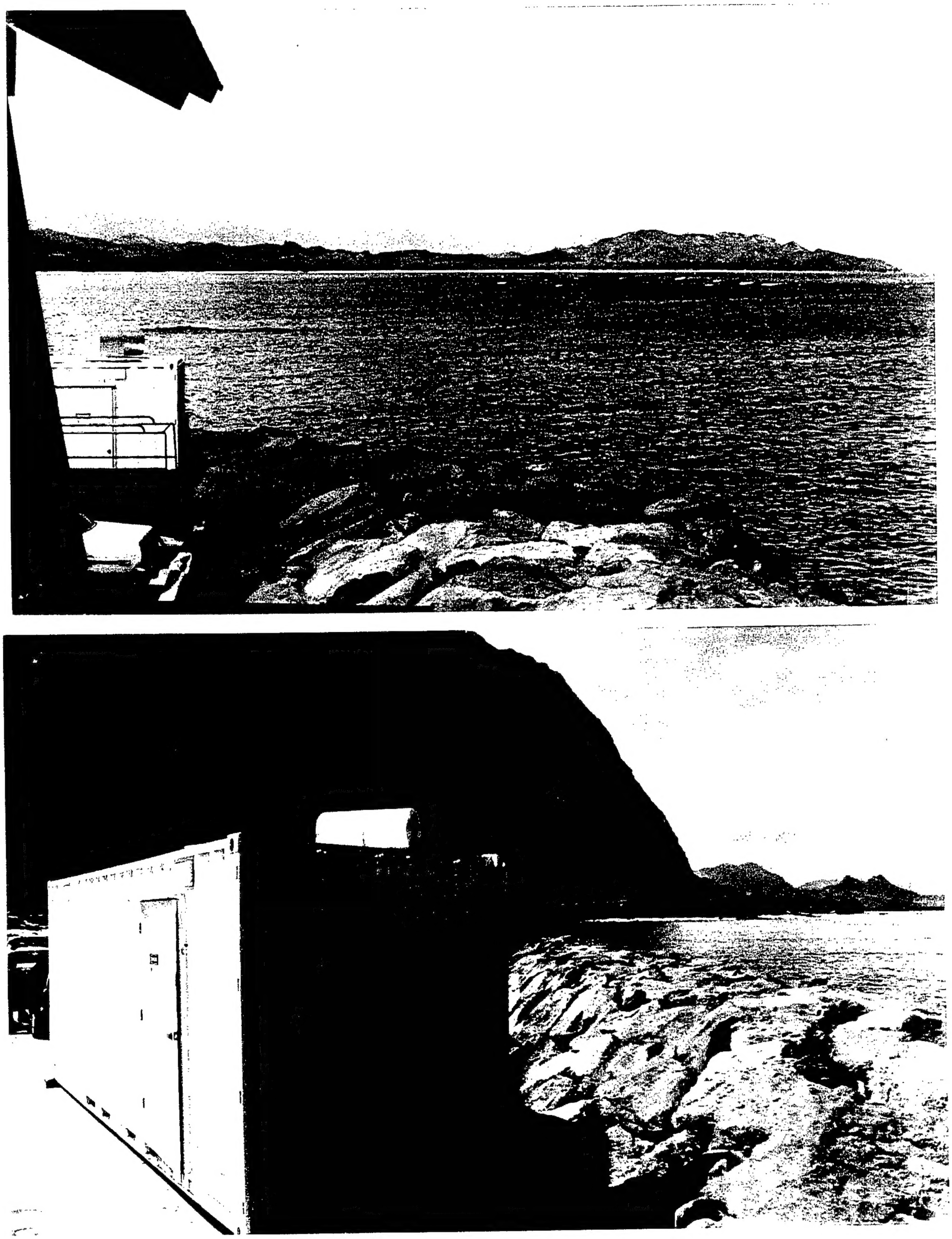

Fig. 4. The LIDAR container at its present site at Makai pier (bottom photograph) as well as a view of Waimanalo Bay, looking northwest towards the SOEST Aerosol Studies group's site at Bellows Beach AFS (top photograph).

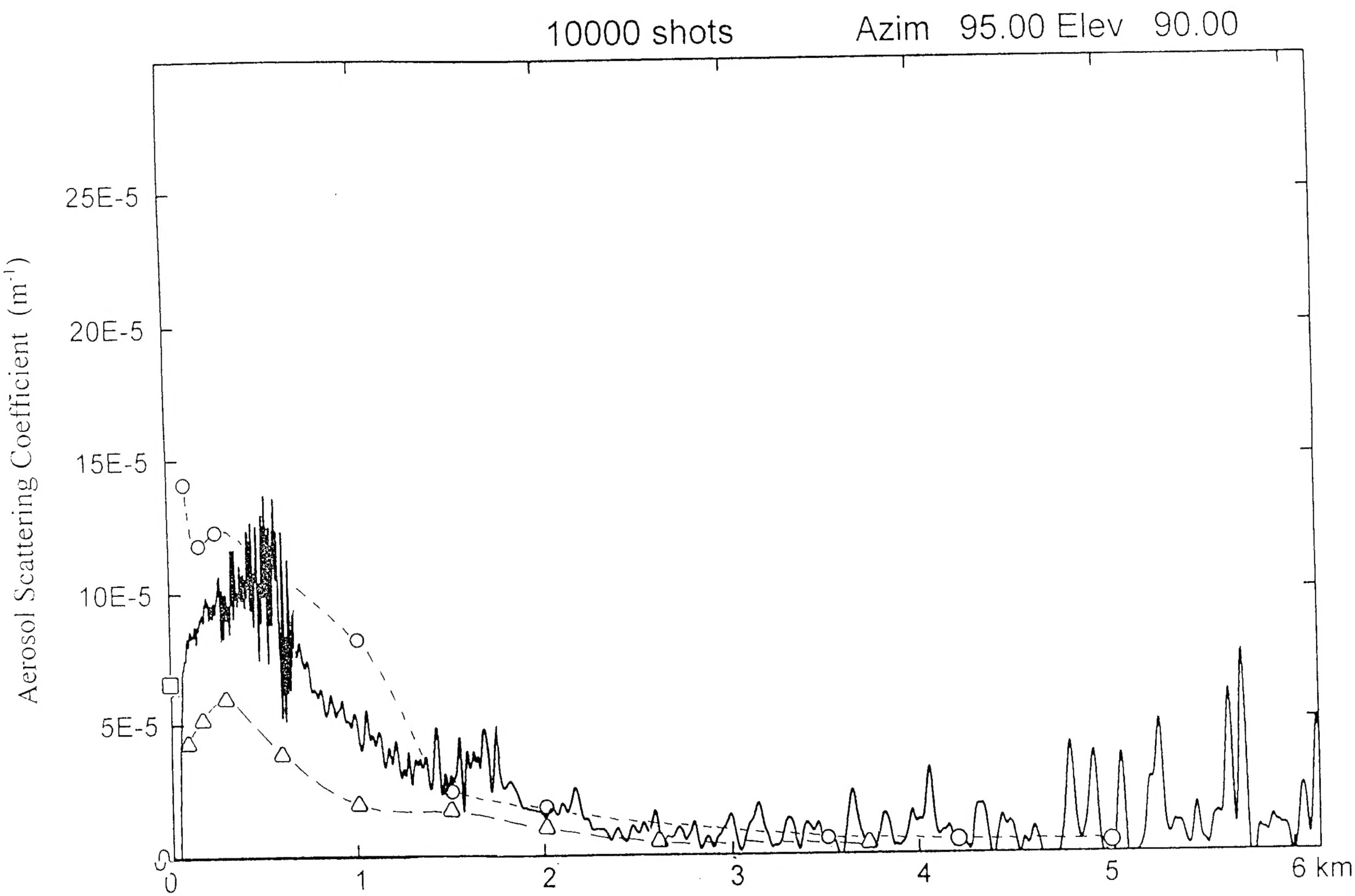

Fig. 5. A composite plot of the calculated aerosol scattering coefficient (m^{-1}) from three 10000 laser (532 nm) shots (500 second) stacks fired at angles of 10, 30 and 90 degrees to the horizontal. For the 10 and 30 degree cases, we have converted slant range to vertical distance to obtain an estimate of the vertical variation in the scattering coefficient. For comparison, also shown are vertical profiles of the aerosol scattering coefficient calculated from aircraft FSSP data collected east of Tasmania (open triangles) in a low-wind regime and off the west coast (open circles) in a high wind regime. The square marks a simultaneous nephelometer measurement of the aerosol scattering coefficient adjacent to the LIDAR container.

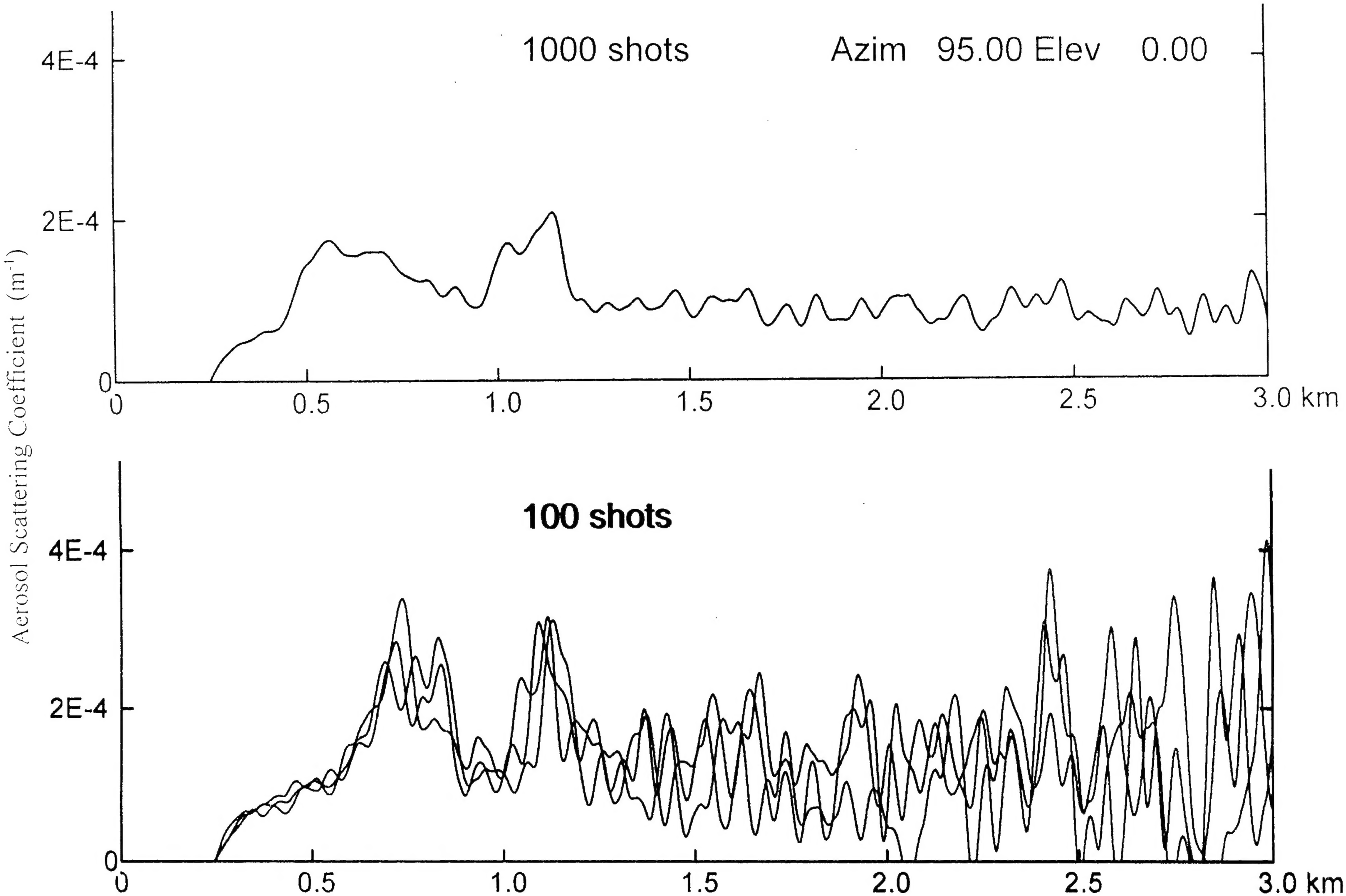

Fig. 6. Vertical profile of the calculated aerosol scattering coefficient (m^{-1}) for 1000 laser shots (top curve), and three sequential 100 shot (5 second) stacks (bottom curve) parallel to and 5 m above the ocean surface. The windspeed was 8 ms^{-1} coming from the Southeast. A digital 4-pole 500 ns low-pass filter has been applied to the data which was sampled in 5 ns wide time bins. The aerosol scattering coefficient for the 1000 shot average varies approximately 30% above the value of 7 - 8 $x10^{-5}$ m^{-1} which was measured by a nephelometer outside the LIDAR container, except at two distances (0.6 and 1.2 km), where waves were breaking over reefs.

infrared region of the electro-magnetic spectrum. We will investigate with our scanning lidar both horizontal and vertical variations in the EO coefficients at various wavelength with atmospheric properties including gas phase species, aerosol concentrations and composition, as well as inhomogeneities in aerosol and water vapor fields. A major field experiment is planned for the end of March 1997 with these sensors.

INVENTIONS: None

PUBLICATIONS AND PRESENTATIONS: The instrumentation acquired under this grant has allowed us to collect field data for following two papers, presented at a meeting organized by the Optical Society of America during Feb.10 - 14, 1997, Santa Fe, New Mexico.

(i) B. Lienert, J. Porter, S. Sharma, A. Clarke and T. Cooney, " Preliminary measurements of vertical and horizontal variation in marine aerosol backscatter in Hawaii", in *Optical Remote Sensing of the Atmosphere*, Vol. 5,, 1997 OSA Technical Digest Series (Optical Society of America, Washington, D. C., 1997), pp. 45-46.

(ii) J. Porter, B. Lienert, S. K. Sharma, T. Cooney and A. Clarke, "Deriving Aerosol properties from combined passive and active measurements" in *Optical Remote Sensing of the Atmosphere*, Vol. 5,, 1997 OSA Technical Digest Series (Optical Society of America, Washington, D. C., 1997), pp. 21-22.

NUMBER OF GRAD STUDENTS, POST DOCS: None

This was an instrumentation grant and did not include any support for students or post-doctoral fellows. It is anticipated that these atmospheric sensors would provide training and research opportunities to students (both graduate and under-graduate) and post-doctoral fellows as well as to high school teachers in the near future.